Remote Sensing Information Visualization Using Volume Based Objects in World Wind

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***Abstract*—Visualization of remotely-sensed meteorological data has traditionally consisted of two dimensional maps. However, the technological advancements in recent years have allowed data to be collected in new and unique ways and with greatly increased range and density. In particular, data are now collected at discrete locations within a volume, as opposed to points on a surface. The data volume, as opposed to an image, necessitates a different form of visualization. Unlike common techniques that stick on two dimensional maps, the main focus for the new techniques is showing the precipitation and other meteorological data in a more intuitive manner. This paper will introduce one of several possible ways to visualize a volume dataset. In this particular case rain intensity values gathered by NASA's TRMM satellite deliver a stereotypic volume dataset.**

***Index Terms*—visualization, IsoSurface, World Wind, remote sensing, volume visualization, 3D dataset, TRMM, GPM, precipitation**

I. INTRODUCTION

The NASA and JAXA joint venture Tropical Rainfall Measurement Mission (TRMM) is equipped with a measurement instrument named Precipitation Radar (PR). Unlike other radar sensors the PR is able to measure not only in longitude and latitude but also at different altitudes. The data that is gathered by this satellite therefore provides a three dimensional meteorological profile. Rain intensity, temperature or state of aggregation are available at each of the measurement points. However, having this data available and being able to read it easily are two totally different things. This problem is the main focus of this paper. An appropriate visualization is mandatory to make information transparent and readable. In order to find this solution/visualization it is necessary to define first the data of interest and second an appropriate visualization environment.

A. Data Source

The data of interest in our particular case is the radar rainfall rate and profile 2A25 [1]. Stored as Hierarchical Scientific Data Files (HDF) [2] they are freely available through the Goddard Distributed Active Archive Center [1]. Each file provides approximately one orbit consisting of 9249 swaths. Each swath has an on-ground separation from the previous swath of 5km. One swath itself consists of 49 beam positions respectively, a resolution of 49 measurement points with a distance of likewise 5km to each other. With the PR however each beam position has 80 altitudinal measurement points over a spread of 20km. Therefore each swath has an observation scope of 245km horizontal and 20km vertical. This can be considered as a three-dimensional grid of vertices each with rainfall rate as its payload.

B. Visualization Environment

The decision on a visualization environment was rather easy. The needs that had to be served included, besides others, the ability to georeference the data and potential visualizations. This includes scaling, rotating, translating and deskewing of the given data to match its original size and position relatively to its environment. NASA provides a good platform for research and development for such earth-centric presentations. Their open source application program World Wind [3] ingests the most often used geo-referenced data sources. As a commonly known and used application, the resulting visualization will be easily available for a broad group of potential users. The standard installation of World Wind is already making the first step in the right direction by wrapping the well known two dimensional maps around a sphere, making it possible to take a step back and look at the globe and its landscapes in a more natural way. However, wrapping a map of rainfall intensity around a globe does not present the data in the most intuitive fashion. It is a lot more useful to look at the precipitation as filling a volume, meaning different intensities dependent not only on longitude and latitude but also on altitude.

This points to the need for volume based shapes. Volume graphics is the next step to bring more value to a visual information representation of precipitation. Volume graphics have already proved useful in other scientific domains. In medical science the visualization of computerized tomography data using volume graphics is well established [4]. The format for a volume of precipitation is basically the same as the data in medical tomography: a three dimensional array or point-cloud with scalar attributes at each point, as already given through TRMM's HDFs.

II. Realization

In the following section we will present our visualization technique, which was developed as a plug-in to World Wind. The techniques that are used, as well as the visualization pipeline, will be described.

A. Visualization

The input is defined as a multidimensional array, with three dimensions for spatial or volumetric spread plus an additional value that represents the payload for each vertex in this grid. The output is a shape represented as a polygonal net, which can be rendered using Direct3D or OpenGL. To describe the needed transformation we can assume the input grid is a steady "data block". Metaphorically the goal is to carve a surface out of it with the help of a given threshold. In this particular case the threshold will be within the rain-intensities range (0-300mm/h). Through the applied process an iso-surface is formed, which represents exactly the threshold within the given dataset. The iso-surface is a polygonal structure which equals a three dimensional contour. Operating repetitively on the same dataset with different thresholds, a multilayered visualization is achieved. Those processed iso-surfaces are also placed relative to their geographical position aligned to World Wind's virtual earth surface.

B. Processing Pipeline

World Wind itself is implemented in C# using the .NET Framework and the DirectX graphical API Direct3D. Processing of the volume dataset in the core is handled by an efficient C++ implementation of the contouring algorithm marching cubes [5]. It is included in Visualization ToolKit's (VTK [6]) C++ libraries. The processing pipeline that is constructed consists of three steps: reading the data source file; calculating the iso-surface to a given threshold; displaying the polygonal surface. However, due to the fact that the visual representation and the data processing are being accomplished using two different programming languages, the pipeline includes more granular steps. Especially because the languages do not share a common structure for polygonal data objects such as triangles or triangle strips, the transfer is not easily accomplished from one language to the other. Knowing this issue the data has to be broken down to the lowest interchangeable format. The processing pipeline is thus composed as follows: read raw data; build structured grid; operate marching cubes contour filter; extract iso-surface points and normals; return them to World Wind; reconstruct the polygonal volumetric object; and render the object.

In order to achieve the desired processing pipeline, a part of the original VTK pipeline is adopted (See figure 1). The visualization preparation and final rendering, that are usually included in this pipeline are unnecessary because the visual part will be accomplished by World Wind as part of the graphical interface.

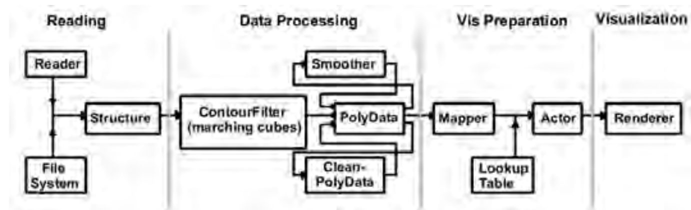

Fig. 1. VTK Pipeline

C. Plug-in

A prototype implementation has been developed. The pure visualization part of the World Wind plug-in named **Rain-Intensity3D** operates only in C#, whereas the complete data processing, storing- and reading-process are accomplished in an encapsulated C++ dll using VTK's libraries and powerful algorithms. This allows C# to access and interact with the C++ implemented methods and take advantage of direct processor operation.

The plug-in itself can easily be installed and used in the same way other World Wind plug-ins operate. A set of different parameters belonging to each iso-surface representation in World Wind enable the individual modification of each iso-surface. Figure 2, 4 and 3 shows the effect of modifying each parameter. The parameters affect the altitudinal stretch, the altitudinal resolution of the source grid, the rain-intensity (threshold) that is used to build the iso-surface, smoothing, color and transparency of the iso-surface.

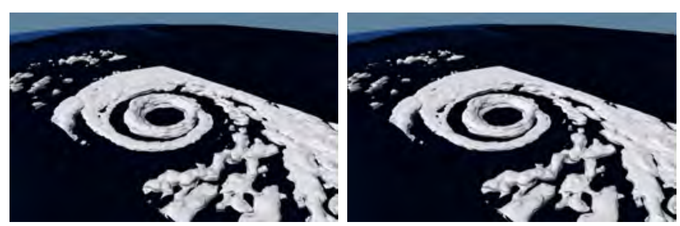

Fig. 2. Plug-in parameter results: standard (left) and smoothing (right)

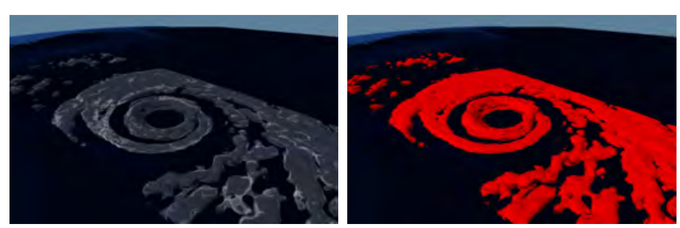

Fig. 3. Plug-in parameter results: transparency (left) and color (right)

A multilayered visualization of the same dataset but with different thresholds is shown in figure 5. It illustrates the ratio between the different rainfall rates in comparison to each other.

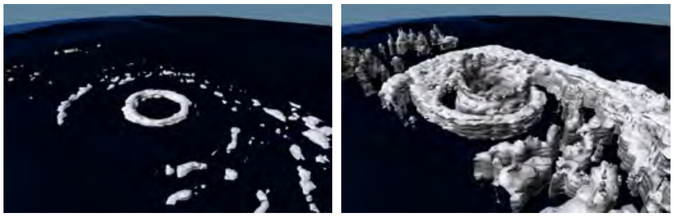

Fig. 4. Plug-in parameter results: rain intensity threshold (left) and height stretch (right)

The plug-in allows the user to add multiple iso-surfaces with independently adjusted parameters for different datasets at the same time, and alter and delete ad libitum.

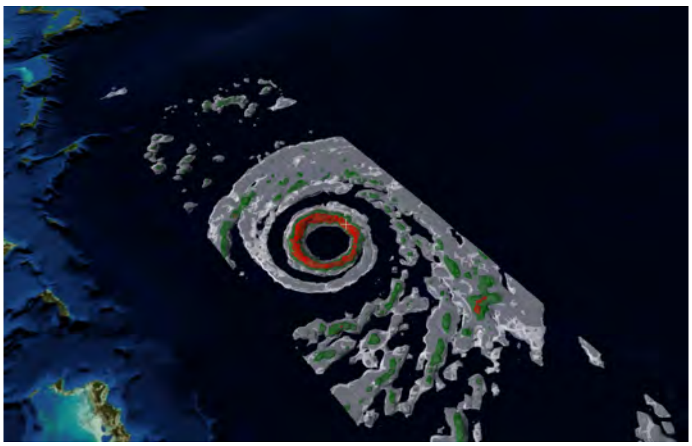

Fig. 5. Multilayered Iso-Surfaces (gray 3mm/h, green 20mm/h, red 60mm/h)

Figure 6 shows an example where the need of transparency becomes obvious. Only the transparency of each iso-surface enables the viewer to see through this multilayered representation and investigate ratios for example. The particular visual representation is also altered though smoothing its polygonal structure. This distorts the original data but provides a plus in representation and interpretation, which can be as beneficial as the stretched altitude spread that was applied in figure 7.

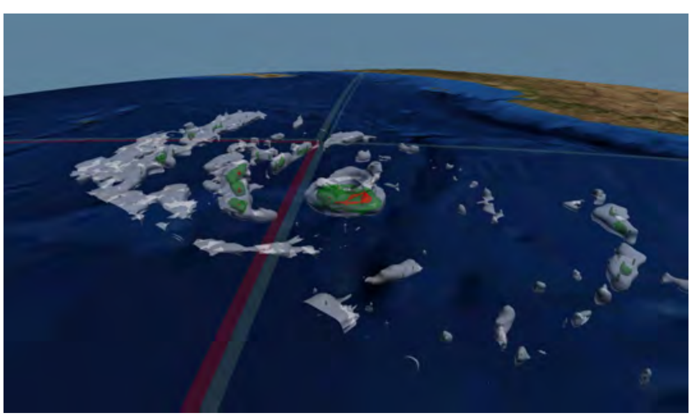

Fig. 6. Smoothed multilayered Iso-Surfaces

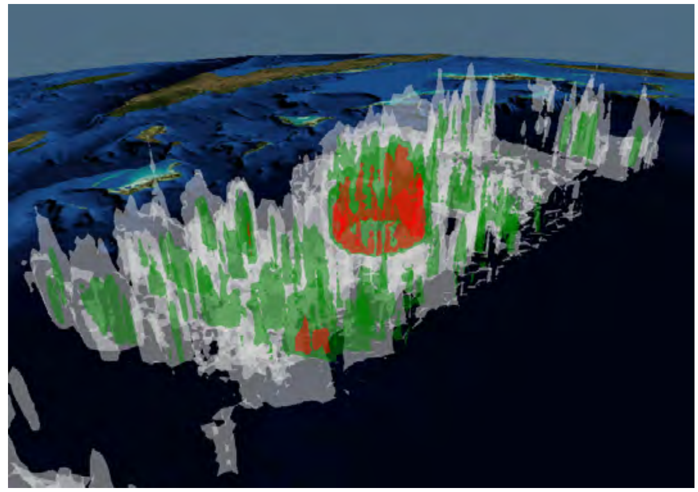

Fig. 7. Stretched multilayered Iso-Surfaces without shading

III. Conclusion

A. Transferability

The marching cubes technique and the resulting iso-surfaces have value in observation and analysis of meteorological data. The fundamental technique that has been used to process the precipitation three dimensional data grid can be used to visualize other three dimensional data sets. The attained knowledge is not bound only to NASA's World Wind framework. Applications in different environments are also both imaginable and possible. Google Earth for example would be another 3D virtual earth environment which is equipped with the necessary abilities, like georeferencing or polygonal visualization.

B. Independency

This visualization was accomplished using object oriented development and code logical separation according to the Model View Controler principles (MVC [7]). Following these guidelines made the source code feasible for any further changes and adaptation. The chosen architecture divides the plug-in itself into encapsulated sections which all serve their own purposes. This enables an uncomplicated replacement of each section, for example, an exchange of the graphical environment libraries from Direct3D to OpenGL.

One near future adaption that needs to be done is to apply minor changes to fully support the new Word Wind version 1.4 and consequently the .NET framework 2.0. This is indispensable in order to ensure support for further versions.

C. Valuation

How valuable this visualization is can not be said in general. The jury for answering this question will be found in the research community that has interest in the particular data. The obvious benefit is that the visualization enables the analyst to observe the dataset's ratios. Furthermore he has the ability to observe the specific dataset from every angle and view that can be interesting, where possible additional information can be drawn. To accomplish the visualization no revolutionary new techniques have been used, but the way those available techniques have been used is new. With the help of the NASA's virtual earth environment World Wind, which is freely available to everybody, an interactive three dimensional meteorologic data visualization is provided – a visualization that is not a static single image processing solution.

However it has to be mentioned that the visualization itself is only as good as the input data is. The example dataset has an on-ground resolution of 5km, a rather large step width in relation to the altitudinal resolution of just 0.25km. Techniques like smoothing of the resulting iso-surfaces (see figure 6) or interpolation of the given volume dataset can make the final visualization look better, but it is a distortion of the given raw data.

A further point that needs to be made is that even though the visualization now does appear to be a cloud, it is not. The viewer must always be aware that the specific visualization he is using is a set of iso-surfaces.

IV. Further Work

In this particular work only the intensity of rain was studied. Having the possibility to visualize three dimensional data with a volume graphics approach within NASA World Wind, the horizon is already broadened to find ways to visualize other three-dimensional data sources in the most appropriate way. Data from ground based weather observation stations, or even oceanographic data, are imaginable. With the planned launch of the Global Precipitation Measurement satellite GPM [8] another precipitation radar named Dual-frequency Precipitation Radar, or DPR, will deliver volume datasets with even more coverage than just the tropical regions.

Another way to obtain new three-dimensional datasets is by combining different datasets. Rain-intensity above a specific threshold combined with a temperature below 0°C is a simple example. The value extends well beyond just visualizing volume datasets. Being able to see the relationship between two- and three-dimensional data could be of great value for scientific research. For example how factors of state of aggregation, aerosol concentrations and types, temperature or wind speed influence the rain rates.

Another extension that would be equally useful would be to apply textures to the iso-surfaces. Data source for these textures can, for example, again be the same as mentioned in the previous section. Visualizing the temperature spread and ratio within the iso-surface of a particular threshold could be one of numerous useful approaches. Exploiting 3D textures could be useful and feasible.

The spatial resolution of the available data is often too low. The reason for this low resolution is related to physical and technical limitations. Hence further work that advances the application of reconstruction filters [9] to get more data points and therefore a higher resolution would be useful. This higher resolution of the input data would result in a better, more detailed visualization.

Appropriate future work would also include developing a new virtual environment that exploited volume textures, software rendering, and ray-casting techniques to create high-quality visualizations.

The visualization approach can also be expanded through the visualization of two dimensional slices through the volume, with color gradient textures or with iso-lines on these slices, or even both. Similar approaches have been developed using Kitware's ParaView [10], which is basically the VTK routines with a GUI and parallel rendering modules.

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